Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

OPTIMUM WATER RESOURCE DEVELOPMENT:

A Preliminary Statement of Methodology for Quantitative Analysis

Ivan M. Lee

CALIFORNIA AGRICULTURAL EXPERIMENT STATION
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS

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FOREWARD

The research on which this report is based has been partially supported by the Water Resources Center, University of California. The approach to quantification suggested is regarded as tentative and, accordingly, subject to modification as research progresses. It will be apparent that the statement is incomplete with respect to important details.

The conceptual model outlined assigns to economic criteria a dominant role in appraisal of water resource development. Certain institutional restrictions having an important bearing are recognized but are not given prominence in this preliminary statement. It is, however, an advantage of the activities analysis method outlined that important institutional restrictions can be incorporated explicitly for systematic analysis. It is felt that analyses which may be regarded as "unrealistic" due to the failure to make explicit the institutional restrictions exogenously imposed are not without interest from the policy point of view. Indeed, a meaningful comparison of economic product forthcoming from a collection of economic activities in alternative settings with and without institutional restrictions may be regarded as of key importance to water development policy appraisal.

Neither specific literature reviewed nor individuals consulted, which jointly have provided the background for impressions reflected in the formulation, have been cited in this preliminary statement. Subsequent reports on research progress are contemplated in which specific acknowledgment and subsequent modifications in the conceptual model will be included.

OPTIMUM WATER RESOURCE DEVELOPMENT

A Preliminary Statement of Methodology for Quantitative Analysis

by

Ivan M. Lee[1/]

The purpose of this statement is to set down in orderly form certain tentative ideas bearing on the quantitative economic analysis of water resource development. More specifically, the problem to be analyzed concerns optimum water development in California. The points developed have in view a comprehensive problem for the state as a whole. In the exploratory attempts at quantification, however, it is planned to restrict the scope of the problem to more manageable proportions but at the same time retain a number of the features which would be present in the more comprehensive problem. Although a specific exploratory problem has not yet been defined precisely, a possible orientation is suggested by the remarks in the final section of this statement.

Since formal activity analysis provides a natural framework within which to explore optimization problems under resource limitational constraints, much of the discussion in this statment employs terminology of programming methods. It is not the intent, however, to emphasize the techniques of programming solutions but to focus attention rather more on quantitative adaptation to the problem at hand.

Actually, formulation of the problem in a framework for quantitative analysis may be largely divorced from considerations of data availability since acquisition of data meeting the specifications of the underlying model may be considered as an essential subsequent phase of the research procedure. In the present statement, however, abstract specification of the model supplemented by discussion of data required ideally is not regarded as an acceptable terminal point. Furthermore, it is not regarded as advisable at

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1/ Associate Professor of Agricultural Economics; and Associate Agricultural Economist in the Experiment Station and on the Giannini Foundation.

[illegible] RESOURCE DEVELOPMENT

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this stage to propose launching out on an extensive program of data collection and comprehensive analysis if through some compromises with ideal specifications of the model fruitful exploratory analyses seem possible on the basis of data relatively accessible. At the time of this writing, a good deal but by no means all relevant background literature has been reviewed, and it is the impressions emerging from this review which underly the formulation suggested. No claim is made to having at this point a complete and detailed picture of specific data available for carrying through an actual analysis. Accordingly, modifications in approach may well emerge as the study progresses and exploratory analyses take more specific form. On the other hand, the general impression gained thus far on types of published and unpublished data accessible suggests that meaningful analysis may be possible at a fairly comprehensive level of aggregation. It is proposed that an attempt be made in this direction. Should it develop that useful substantive results are not forthcoming from the exploratory work, it is hoped that the attempt at systematic analysis will at least have been helpful in focusing attention on the deficiencies in information and methodology which need to be remedied before more useful results can be expected.

Statement of the Problem

As stated above, the problem engaged here is one of economic optimization. Water input used in agricultural as well as nonagricultural activity is "produced." Water supplies relatively accessible may have rather low associated costs of production. A part of the water input, such as that resulting from rainfall which serves effectively to replenish surface soil moisture, may be regarded for purposes of our problem as a "free" resource and beyond allowing for its effects need not be incorporated explicitly in our analysis.

The following may be regarded as the major potential sources of produced water in California: (1) captured surface runoff, the major potential for which centers in the northern portion of the state, although potential for surface development in selected local areas still remains; (2) pumping from underground reservoirs; (3) reclamation of sewage; (4) increased re-use of industrial water, particularly in the heavy water using industries; (5) elimination of "wasteful" excess of water input in those conditions where physical factors obstruct or do not directly facilitate re-use at a later point along the route to ultimate discharge in the ocean; and (6) conversion of sea water. Which of these constitute "efficient" sources of supply depend upon economic considerations. It is in fact a part of the economic optimization problem to determine which of the potential supplies are to be drawn upon as inputs in the production of goods and services. It should not be surprising if certain sources which are efficient in one section of the state are not efficient in another section.

An important consideration bearing on water resource development in California stems from the fact that the major potential for capturing surface water is in the northern part of the state while the potential for economic development lies to the south, including the heavily industrial South Coastal area some considerable distance away. Production of water through capture of north-state surface runoff constitutes a productive activity involving very substantial initial fixed investment resulting in the creation of physical facilities capable of supplying a continuing stream of input over a long period of time. The water conveyance system necessary for the distribution of the water input to areas of economic development implies an additional substantial initial investment in a production facility with long life. Heavy fixed investment in the face of economic risk and uncertainty in the long run coupled with the complex distributional welfare considerations associated with water

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An important consideration bearing on water resource development is initially drawn from the fact that the major potential for developing additional water is in the northern part of the state while the potential for economic development lies in the south, involving the heavily industrial South Coastal area some considerable distance away. Production of water through capture of north-state surface runoff constitutes a productive activity involving very substantial initial fixed investment resulting in the creation of physical facilities capable of supplying a continuing stream of input over a long period of time. The water conveyance system necessary for the [illegible] of the water input to areas of economic development implies an additional substantial initial investment in a production facility with long life. Heavy fixed investment in the face of economic risk and uncertainty in the long run coupled with the complex distributional welfare considerations associated with water

development in this and similar physical settings may be regarded as constituting the bases for a heavy degree of direct state and federal involvement in water resource development over the years.

Appraisal of public versus private investment policy is not of direct concern here. However, the orientation of the problem toward development implies that investment optimization occupies a central place in the analysis. It will be convenient to regard the problem as one of comparing the magnitudes of economic product forthcoming from alternative lines of investment of a given volume of investment funds. Distributional welfare considerations will be disregarded at this stage. Clearly a full analysis of the problem involves comparison of returns to investment in various alternative lines of which water projects consitutes one alternative. It is not proposed here to undertake quantitative analysis of nonwater investment alternatives. However, comparison of alternative water projects is contemplated ultimately.

The approach proposed involves defining objectively an economic criterion for the state as a whole with respect to which the optimization problem will be considered. The criterion defined is a dollar measure of net economic product. Implicit in the conceptual framework are rules requiring that the product forthcoming from the development and use of an additional increment of water must cover incremental costs including return on investment and requiring that rate of development over time as well as allocation over space must be such as to maximize the objective criterion.

The economic product associated with a given major water development project characteristically takes the form of a composite of commodities forthcoming from several uses of the captured water resource. Product resulting from direct input of water in residential, industrial, and agricultural uses is an important component. In addition, there may be important contributions to total product in the form of flood control, navigation,

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hydroelectric power generation, and recreation. It is understood that productive use of the water resource need not imply direct water input in a technical production process since indirect uses such as for repulsion of sea water from surface streams or from underground reservoirs must also be included among the economic alternatives.

Among the rather heterogeneous array of identifiable forms of product, certain forms lend themselves more readily to measurement in terms of criteria of the market than do others. Furthermore, the particular combination of products to be generated by a particular project depends directly upon the features built into the project and upon the management of the operation after construction is completed. To a significant extent, the various uses for water are complementary and the criterion defined to measure final product forthcoming should reflect this jointness of product. On the other hand, the alternative uses of water indicated are competitive to an important degree. Accordingly, the structuring of the underlying analytical model and the definition of the criterion should be such as to permit solution for the optimum set of activities from among the competitive alternatives specified.

Although centralized authority and control over investment decisions is not necessarily implied in an approach which treats the state as a single economic unit, it is worth noting that a large measure of central control has accompanied water development in the past and most likely will continue to prevail in the future. A substantial initial investment in the face of risks associated with relatively long-time horizons is characteristic of dam and reservoir construction as well as the vast water conveyance system required to place the water at point of use. Furthermore, optimum development of a given water source area may imply an integrated arrangement of dams and water storage reservoirs for an entire basin. The desirability of integration in the conveyance system is also obvious. These considerations coupled with the

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inevitable distributional welfare problems associated with water development decisions make water projects a rather natural area for a large measure of direct government involvement. The dominance of these characteristics of investment in water projects may be regarded as lending some realism to an approach to measurement which treats the state as a single economic unit.

Analytical Method

As has been indicated, it is proposed to deal with this problem in the formal activity analysis framework. This involves the construction of a large number of alternative input-output combinations defined with reference to sectors and subsectors of the California economy. Each such input-output combination constitutes an activity. The set of activities supplemented by a set of constraints and an objective optimality criterion (to be maximized in this instance) completes the formal specification of the problem. Mathematical programming methods may be brought to bear in obtaining a solution to the problem and the value of the criterion corresponding to the solution constitutes the measure of product forthcoming.

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The following symbolic representation will facilitate discussion of ideas. Define the set of $m = \Sigma_s \Sigma_k J_{sk}$ alternative activities:

$$a_{iskj} = \begin{bmatrix} a_{1skj} \\ a_{2skj} \\ \cdot \\ \cdot \\ \cdot \\ a_{rskj} \\ -a_{r+1,\, skj} \\ \cdot \\ \cdot \\ \cdot \\ -a_{nskj} \\ -a_{n+1,\, skj} \\ \cdot \\ \cdot \\ -a_{n+q,\, skj} \end{bmatrix}$$

Coefficients a_{iskj} represent quantities of commodity $\underline{i}$ entering activity $\underline{skj}$. Subscripts $\underline{s}$ and $\underline{k}$ refer to major sectors and subsectors, respectively, with $s = 1, 2, \ldots, S$ and $k = 1, 2, \ldots, K_s$. Subscript $\underline{j}$ refers to the

activity defined for a given subsector, $j = 1, 2, \ldots, J_{sk}$. For some subsectors J_{sk} may equal 1, that is, only a single activity is defined. The subscript i denotes commodity entering the activity, $i = 1, 2, \ldots, n+q$. In the amplified vector above, commodity aggregates have been designated with $i = 1, 2, \ldots, r$ representing outputs; $i = r+1, r+2, \ldots, n$ representing nonlimitational inputs; and $i = n+1, n+2, \ldots, n+q$ representing limitational inputs. It is convenient to regard input coefficients as negative.

All quantities in the above matrix may be regarded as measured in physical units. Define p_i for $i = 1, 2, \ldots, n$ as the price, assumed given, of commodity i. Then $\sum_i^n p_i\, a_{iskj} = x_{skj}$ is the measure of economic product associated with activity skj. The alternative activities now consist of a combination of a measure of net product and a set of limitational inputs. By an appropriate proportional adjustment in product and corresponding limitational inputs, a unit level activity may be defined such that the measure of product is equal to some convenient figure x for all skj.

Let z_{skj} denote level of activity j subsector k, sector s in the optimum solution. Define $V = \Sigma_s \Sigma_k \Sigma_j z_{skj}$ as the criterion of optimality. The optimizing solution consists of determining z_{skj} such as to maximize V under constraints $z_{skj} \geqq 0$ and various constraints reflecting availability of limitational inputs. The constraint on a given limitational input ($i = n + 1, n + 2, \ldots, n + q$) may take any one or a combination of several forms: a limitation on availability for the state as a whole $\Sigma_s \Sigma_k \Sigma_j a_{iskj} z_{skj} \leq c_i$; limitation on availability for a major sector $\Sigma_k \Sigma_j a_{iskj} z_{skj} \leq c_{is}$; a limitation for a subsector $\Sigma_j a_{iskj} z_{skj} \leq c_{isk}$; or some combination of these various forms. The aggregate product forthcoming from the optimal program is measured by Vx.

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Nonlimitational input

The nonlimitational inputs envisaged in this formulation consist of charges against product such as depreciation on fixed equipment and various materials costs. The assumption of a given price for these inputs is equivalent to assuming that the relations describing supply of inputs to California producers in the aggregate are perfectly elastic within the relevant range. To allow for other forms of supply relations would have the effect of introducing nonlinearity into the criterion to be maximized.

Limitational input

The major types of input which it would seem important to recognize explicitly as limitational are irrigable land, labor force, and the water resource itself. Irrigable land is, of course, not absolutely fixed in area. Virtually any piece of land is irrigable at a cost. It should be possible, however, to arrive at an operationally useful definition of irrigable land by excluding those land areas obviously "inefficient" under the economic conditions relevant to the problem. Land not clearly inefficient should be included in the available land resource. Whether or not such land is in fact efficient is revealed by the optimal solution. It is suggested below that land characteristics enter as criteria for defining subsectors, particularly in agriculture-based activity. Accordingly, for much of the agriculture-based activity limitational constraints on land area will be defined for each subsector.With reference to nonagricultural activity, however, land constraints may be defined more generally for collections of subsectors.

For the planning horizon implicit in water resource development population growth in California cannot strictly be regarded as independent of economic growth and, perhaps, more specifically of the availability of the water resource. On the other hand, it is by no means clear a priori that water availability will be the dominant factor governing population growth.

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A broader model encompassing several regions might be so structured as to permit direction of migration for a given state or region to be endogenously determined. In such a model the regional distribution of population emerging would be that distribution required to locate the labor force in conformity with the optimum location of economic activity. Although interregional migration in the long run is unquestionably sensitive to economic opportunity, there undoubtedly remains a significant degree of rigidity or immobility which must be reckoned with. The existence of even partial immobility implies some form of limitational constraint on population growth in a given state or region. The imposition of limits on size of labor force is regarded as the most reasonable way of dealing with this problem in a partial model such as the model for California here developed. The consequences of modifications in the labor force constraint can, of course, be explored systematically. Accordingly, substantive results may be sought for a range of plausible assumptions concerning population growth. The prices for labor implied in program optima under alternative conditions specified promises some basis for conjecture on whether the in-migration rate implied by a given limitational constraint is consistent with relative economic opportunity. In the extreme case, for example, where labor emerges as a "free" resource there is clearly basis for questioning whether the limitational constraint imposed is compatible with reasonable assumptions regarding economic opportunity. While claiming merit for this way of treating the labor resource in a partial model, awareness of the inferiority methodologically of this approach as compared with the broader model which incorporates explicitly the interregional relationships should not be lost.

A combination of constraints by major sectors and for the state as a unit would appear to be more plausible in the case of labor. Constraints by major sectors imply intrastate immobility, an assumption which would seem realistic for at least a significant component of the California population. At the same

time, a substantial floating population is necessary in analyses designed to have implications for longer run development and growth in order to avoid "built in" geographic patterns of industrial location. The allowance for floating population may be achieved by superimposing upon the major sector labor constraints additional constraints with respect to the remaining component of the labor force for combinations of major sectors or for the state as a whole. It will be apparent, however, that the formulation developed in this preliminary statement does not adequately incorporate other important factors bearing on intrastate industrial location.

Finally, the approach adopted to the problem dictates that the water resource be treated as limitational. It is the objective of the analysis to compare total product forthcoming from investment in alternative lines of water development. It is noted that whereas other limitational resources may enter the formal framework in physical units, the water resource is to be specified in "dollars worth." The monetary unit is convenient for water since it is necessary to reflect in the specifications the fact that a given physical unit of water represents a different level of economic input at points of use further removed from the source of supply than at points closer to the source due to conveyance costs involved in placing the water input at point of use. Since conveyance cost is a part of the production cost of water, it is necessary to recognize this explicitly in formulations designed to explore economic optima. It follows that the limitational constraint on the water resource can be most conveniently handled by specifying alternative limits on total cost of facilities measured also in monetary units.

A water limitational constraint, defined with reference to the state as a unit, is the appropriate form if geographic and product-wise allocation is to be determined without regard to institutional restrictions. On the other hand, explicit introduction of institutional restrictions implies definition of

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water supply constraints for major sectors or perhaps collections of subsectors within major sectors.

Output

The specification of multiple products for a given activity allows explicitly for joint products. The inclusion of certain primary joint products may give rise to special problems in defining activities. The complications implied are considered briefly in a later section. It may also be noted that allowance for joint products provides a convenient framework for making explicit the re-use of water as input "internally" (within the given activity) or "externally" (as input in other activities). These possibilities are also considered more specifically later. Finally, the aggregation procedure discussed below is equivalent to treating the combination of a principal product and a set of secondary products as joint products in a single aggregate activity.

The assumption of given prices of product in the criterion, as in the case of nonlimitational inputs, implies infinite elasticity of demand for a given product produced by the aggregate of California producers. The acceptability of such an assumption is, of course, highly questionable and would seem off hand less acceptable than its counterpart on the nonlimitational factor supply side. This suggests that even relatively crude analyses in the framework proposed should recognize explicitly nonlinearity in the criterion arising on the demand for product side. This is probably of most direct relevance for agricultural products. Inequality constraints on volume produced under rigid prices may approximate conditions reasonably well for most nonagricultural commodities.

Extension in time

The problem of appraising alternative investment decisionshas, of course, both time and space dimensions. Only the space dimension is made explicit in the above specifications. Introduction of the time dimension is achieved symbolically by the addition of a t subscript, $t = 0, 1, 2, \ldots T$, to each of the technical coefficients, to each of the supplies of limitational resources, to each price, and to each activity level. In general, the relationship among expected prices, the supplies of limitational resources (for example, the labor force), and the technical coefficients entering the activities (technology) would be different for different t. The comparison between alternative investment programs could in this case be in terms of discounted value of product with the criterion to be maximized summed over t. Under certain rather restrictive conditions involving uniform price relationships, constant technology, and constant supplies of limitational resources, the use of discounted values permits collapsing the time dimension for investment comparison purposes. However, such restrictive conditions, although convenient in initial, exploratory analyses, will ultimately have to be relaxed since their adoption precludes analysis of some of the most relevant factors effecting direction of economic development.

In the time dimension,risk also enters to complicate the formulation and analysis. Risk may be regarded as associated with projections of relevant variables beyond point t_0. Decisions concerning investments with economic life on the order of that confronted in water development involves very long-run projections with which there is inevitably associated a significant risk element. Elaboration of the model to include risk explicitly is not undertaken here. Formulation of the model to deal explicitly with risk is conceptually possible,but experience with projection of economic variables in time does not give basis for a high degree of confidence in the underlying specifications,

[illegible]

particularly in the longer time periods relevant to decisions with respect to water development. Accordingly, failure to adhere strictly to objective procedures in dealing with risk in the operational problem cannot be regarded as a particularly crucial weakness of the method. A device sometimes employed for introducing risk operationally involves adjustment of the discount rate to include a risk allowance in addition to interest. Alternatively, a range of plausible assumptions may be substituted for a single projection with the objective of providing a "useful" range of optimum solutions rather than a single best solution. Implications with respect to measurability of risk are, of course, different for these alternative approaches.

The criterion which is to serve as a measure of product flows over time for comparison of alternative investment opportunities should reflect an optimum allocation of the water resource at each given point in time and further an optimum rate of investment over time taking account of such factors as expected growth in demand for product, expected change in supplies of limitational resources, and expected technological change. Strictly speaking, optimum allocation at time t is not independent of flows over time since it may be economic to deprive use j^* of water at time t in order to provide use j^{**} with water at time $t + \gamma$. This may be regarded as of particular relevance to water development if the plan is to allow for the possibility of drought years when "excess" surface or ground water carried over from previous years is to be made available for use in years of "shortage." Explicit formulation of a dynamic model is implied for a proper recognition of such relationships in time.

Adapting the General Specifications to Operational Form

The above abstract symbolic representation and comments provide the general framework within which the operational problem is to be placed. Precise

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results from such a model imply that a very good deal must be known about the underlying technical production and demand-for-product relations and, for extension in the time dimension, relations yielding acceptable time projections of the crucial limitational variables and technical coefficients. Indeed, if the technical production relations were known, then for a given price structure the optimum combinations of inputs required for precise definition of activities could be derived. In these circumstances, it would still be convenient to forumlate the problem in terms of a number of discrete alternatives, however, and introduce explicitly the limitational constraints.

In the remainder of this statement, attention is focused on concepts and procedures which bear on the adaptation of the problem to the general framework specified. Most of the subsequent development disregards the time dimension of the problem and concentrates on questions of allocation in space both geographically and productwise. As has been indicated, extension in the time direction is possible conceptually, but measurement problems promise to be somewhat more difficult. The points developed here are, of course, relevant to the more general problem. In a subsequent section, a further amplification of selected activities in symbolic form is undertaken to illustrate certain of the ideas discussed.

Clearly, one needs to be prepared to tolerate substantial compromises with ideal specification if an attempt is to be made at quantitative analysis employing the types of data relatively accessible. On the other hand, systematic analysis of simplified exploratory formulations may yield fruitful insights. Furthermore, some attempts at simplified formulations hold some promise of pinpointing the more serious gaps in information and may provide more basis than now exists for discriminating between more serious and less serious deficiencies.

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Aggregation

Adaptation of the model to operational form is achieved largely through aggregation of activities. The linear activity analysis model is regarded as an approximation to that which would be achievable if the underlying "smooth" functional relations were known with, however, the additional realism incorporated in the linear activities model reflected by the several inequality constraints. It is the behavior of microunits in the economy which generates the economic product serving as the criterion for the problem at hand. The underlying economic theory is microtheory. From the point of view of analytical method, the gain in aggregation is assessed in terms of convenience, but in general there is a loss in precision. Aggregation in accordance with suitably chosen rules, therefore, is designed to minimize the loss for a given level of aggregation. Since the discrete activities model may be regarded as an approximation to the continuous smooth functions case, the same rules of aggregation would be applicable in either case. Hence, the aggregates defined should constitute suitable aggregates for meaningful statistical estimates of underlying continuous relations should this appear warranted at a later stage. Unfortunately, the types of data available for analysis at least in the exploratory stage are almost certain to force a level of aggregation broader than the optimum.

Aggregation of microunits may be regarded as achievable in two directions--horizontal and vertical. Horizontal aggregation involves aggregation over different commodities at equivalent stages of the production process. Both demand parameters (price and income elasticities) and technical input coefficients enter into the criteria governing horizontal aggregation in the present problem. Activities exhibiting an acceptable degree of homogeneity with respect to both demand and technical production characteristics are regarded as meeting conditions for aggregation into a single activity. We

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do not undertake to define "acceptable degree of homogeneity" more precisely at this stage. Strictly speaking, technical homogeneity with respect to each of the limitational resources is required. Since in fact interest centers more directly on the water resource in this analysis, it is possible that the water input coefficient may be regarded as the dominant technical coefficient governing aggregation on the production side. This is to say that more heterogeneity would be tolerated with respect to the remaining technical coefficients. Since conditions of both demand and technical production homogeneity are imposed, a possible procedure would be to first form sets of commodities homogeneous with respect to demand and then within each such set form subsets meeting the technical homogeneity condition. For exploratory analyses of the problem at hand, the collection of fitted demand relations available in the literature supplemented by considerations of a priori plausibility should provide some basis for aggregation on the demand side. On the technical side also, although the information is far from ideal, a good deal is known. In agricultural uses of water, for example, it should be possible to construct usable measures of water requirements per unit of crop output for different crops for given specifications regarding soil class, climate, irrigation system, etc.

Explicit definition of horizontal aggregates for the present problem has not yet been attempted, although some of the pertinent literature bearing on this problem has been reviewed. Examples of aggregates which might emerge from systematic study of the possibilities are such product collections as deciduous fruits for canning, fresh deciduous fruits, feed grains, meat animals and poultry products, and dairy products. These are agricultural examples. Horizontal aggregation of nonagricultural activities will also be necessary. Here, the information will inevitably be thin. It will be convenient to treat certain of the heavy water-using industries as separate

activities and in fact several alternative activities should be specified for such industries. This suggests a low level of horizontal aggregation for this segment. More comprehensive aggregation governed by demand characteristics and properties of technical input coefficients corresponding to other limitational resources (for example, labor) is proposed for nonagricultural activity with low water requirements.

Vertical aggregation is achieved by summing highly complementary activities. In strict complementarity (proportionality) between two activities, there is no loss from combining the two in a single activity. Indeed, aggregation is necessary if explicit constraints requiring proportionality are to be avoided. Strict complementarity in broadly defined economic activities is rare but a substantial degree of complimentarity may be sufficiently realistic for exploratory formulations. Accordingly, a fairly comprehensive level of vertical aggregation is regarded as plausible in the present problem.

Several examples of plausible vertical aggregation may be cited. The production of livestock feed on farms may be regarded as an activity generating feed input for farm production of livestock and livestock products. This may be carried still another step to regard farm production of livestock and products as an activity generating input for later stages of processing livestock products in the nonagricultural sector. By imposing strict complementarity, all such stages may be collapsed into a single activity. Similarly, fruit production on farms and fruit processing or packing may be aggregated.

It is proposed, in fact, to carry vertical aggregation somewhat further in the initial attempts at analysis. Assume that in a given area it is possible to define what might be called principal lines of productive activity. In agriculture-oriented communities, the principal lines would be production centering around agricultural products at all stages from the raw

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product to the form to which it is brought for shipment out of the area (say, canned products). Required for the production of this principal product is a labor force of a particular size. And required to generate this labor force is a population of larger size. A good deal of the economic activity of a particular community (such as retailing and services) bears a direct relation to the population of the community. This is regarded as providing a plausible basis for merging the outputs and inputs of such activities as retailing and service trades with the activity or alternative activities constructed to represent the principal line or lines of production in the local area. Furthermore, the limitational resource of direct interest in this study is water for which an important use is residential consumption. Hence, this use of water may be regarded as an input required to support the population generating the labor force in the area and included in the aggregate activity as a complementary input. Similar possibilities for vertical aggregation exist in those areas where the principal lines of productive activities are non-agricultural.

Definition of Major Sectors

Definition of sectors is a convenient device for classifying activities in the analysis. Aggregation contemplated will not cut over sector boundaries, but definition of sectors should be based on criteria which are consistent with the rules of aggregation adopted. Major sectors to be defined will have geographical boundaries. The primary criterion for delineation of boundaries rests on consideration of cost of the limiting resource water. In order to incorporate the important economic features of the model associated with the use of north state water as input in south state productive activity, the fact that a given volume of water represents economically an essentially different input the further its use is removed from the north state source of supply must be made explicit. One device for doing this is to measure the

product to the firm to which it is brought for shipment out of the area (say, wasted products). Required for the production of this principal product is a labor force of a particular size, and required to generate this labor force is a population of larger size. A good deal of the economic activity of a particular community (such as retailing and services) bears a direct relation to the population of the community. This is regarded as providing a plausible basis for meeting the labor and inputs of such activities as retailing and service trades with the activity or alternative activities considered to represent the principal line or lines of production in the local area. Furthermore, the institutional resource of direct interest in this study is water for which an important use is residential consumption. Hence, this use of water may be regarded as an input required to support the population generating the labor force in the area and included in the aggregate activity as a complementary input. [illegible] possibilities for vertical [illegible] in those areas where the principal lines of productive activities are non-agricultural.

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water input in dollars worth and require that this measure of input reflect the incremental costs associated with its use in particular areas. Major sectoring on the basis of geographic areas may be regarded as facilitating the measurement of the water input.

There is an advantage to forcing boundaries of major sectors to conform to the boundaries of certain areas defined by the California Department of Water Resources in the research undertaken by that agency in connection with its comprehensive California Water Plan. Certain natural boundaries are suggested from the point of view of costs. The following major areas may be mentioned: (1) Sacramento Valley, (2) San Francisco Bay area, (3) Sacramento-San Joaquin Delta, (4) San Joaquin Valley, and (5) South Coastal area. Measures of incremental cost of water distribution should be possible to construct for such areas. Substantial additional fixed investment in the conveyance system is involved as water is made available to each successive area further removed from north state supplies. For example, the pumping and aqueduct facilities required to move water beyond the Delta and distribute it in the San Joaquin Valley constitutes a major additional fixed investment as well as significant additional operating costs. Similarly, substantial additional costs are involved in moving water over the ridge from the San Joaquin Valley into the South Coastal area. In fact, attempts at measurement of incremental costs should be carried back to investment in dams and surface storage facilities in the source area. The facilities required for capturing and controlling sufficient water to meet demand in only the Sacramento Valley, say, is somewhat less than that required to meet the combined demand in the Sacramento and San Joaquin valleys. Engineering estimates which have been made in connection with the development of the California Water Plan will provide a point of departure for constructing measures of costs. However, assistance from the engineers in developing measures beyond what is derivable from published estimates will be necessary in this phase.

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Measures of cost of the water input per unit level of activity will enter the corresponding activity as the water input coefficient. In areas where other sources of water input are accessible, alternative activities may be defined with appropriate values for the water input. If the alternative activities defined are similar in all respects except source of water input, the activity with lowest water input per unit level activity would, of course, be activated first, and the water input available from the cheaper source would be exhausted before the activity with more costly water input is brought into the program. Thus, the construction of alternative activities becomes the device for introducing alternative sources of water input into the model. Local surface supplies, water pumped from underground reservoirs, water reclaimed for re-use, etc., may each be incorporated in this conceptual framework if conditions suggest that such sources are economically efficient.

Major geographic sectoring only facilitates and does not completely resolve the difficult conceptual problem of measuring the water input in activities internal to a region. It is not implied that the cost of water per acre-foot will be uniform over activities within a region. Indeed, activities further removed from the main aqueduct in the distribution system must be differentiated from those in closer proximity if meaningful results are to be forthcoming. Adequate specification here leads to nonlinear rather than linear programming methods on two counts. First, investment costs per unit capacity is a decreasing function of capacity. And, secondly, for a given capacity operating cost per unit of water delivered is a decreasing function of volume delivered. Hence, the appropriate evaluation of the water input depends upon the vector of activity levels in the optimum program. With respect to procedure for obtaining an optimizing solution, it would seem desirable to recognize the nonlinearity explicitly in this instance. The solution of a sequence of linear programming problems may lead to an acceptable approximation.

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Definition of Subsectors

Boundaries to subsectors will not in general be geographic. Definition of subsectors should, however, also be consistent with the rules suggested above governing aggregation. Subsectoring is simply a device for further subclassification of activities into smaller clusters. The convenience in subsectoring stems from the necessity for imposing certain limitational constraints within more broadly defined resource or product categories.

The following remarks will serve to record certain impressions bearing on subsectoring gained through review of literature thus far. Subsequent more intensive study of the literature may well make necessary some modification of these tentative impressions. Although agricultural and nonagricultural activities will be integrated in the actual formulation, it is convenient to separate them for discussion here.

1. Agricultural Activities.--The convenience in subsectoring here stems from the necessity for imposing certain limitational resource constraints within an over-all constraint such as, for example, on irrigable land. In agricultural production, soil class is an important factor in the water input-crop yield relation. Thus, subsectoring by soil class is consistent with rules for good aggregation. In this connection further geographical subsectoring may also be desirable for adequate recognition of relevant climatic factors. Within soil classes land suitable for recharge of underground reservoirs may also be delineated and placed in a separate subsector thus facilitating the construction of alternative activities allowing for coordinated use of surface and underground storage facilities in an integrated

program. The economic conditions made explicit in the specifications will determine whether activities leading to underground recharge are to be included in the optimal program.

Other situations arise also in irrigation pointing to the desirability of subsectoring on soil class criteria. Certain shallow soil underlain with impervious substrata may be productive under irrigation, but a drainage problem is generated when such land is brought under irrigation. In these cases, activities properly defined must incorporate explicitly the necessary inputs for the drainage system essential to productive agriculture. Inputs for drainage would be considered nonlimitational. The effect of drainage costs is to reduce net economic product per unit level activity and, consequently, to place the corresponding activity in an inferior position for inclusion in the program relative to other activities similar in all respects except susceptability to drainage hazard. Topography is an additional physical factor bearing on potential drainage problem.1/

Both soil class and climate have been mentioned as important determinants in the water input-crop yield relationships and their proper recognition in structuring the problem should facilitate construction of more acceptable input-output combinations representing the range of economically efficient activities. Climate enters in two important respects: (a) crop adaptability and (b) direct evapotranspiration requirement. Clearly, (b) is not independent of (a) since evapotranspiration requirement varies significantly with type of crop. Soil class reflects such things as texture and depth of surface soil,

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1/ Although detailed soil classification has not been undertaken for all irrigable area, moderate success might be expected in delineating larger areas of potential drainage problem in the Sacramento Valley, San Joaquin Valley, and South Coastal area. Sufficiently precise measurement of soil productivity with or without associated fertilizer input is somewhat more problematical. Similarly, the delineation of areas of effective underground recharge promises to be troublesome.

process. The economic conditions now existing in the specific area will determine what activities [illegible], to [illegible] [illegible], are to be included in the [illegible] [illegible].

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characteristics of soil profile, and slope, and bears on production response to water input in several ways: (a) crop adaptability, (b) amount of water required to bring and maintain water content of soil above wilting point, (c) susceptibility to salt accumulation and associated necessity for periodic flushing, (d) potential for drainage problem associated with irrigation, and (e) suitability for recharge of underground reservoirs.

Because of variation in water requirements of crops, crop adaptability on purely physical considerations should be considered carefully in the definition of subsectors and the associated alternative activities. Certain crops can be excluded from selected regions on climatic factors alone. Surface soil depth may be regarded as effectively restricting crop possibilities. Tree crops might generally be regarded as inefficient in shallow surface soils underlain with relatively impervious substrata. The alternatives to pasture on certain shallow surface soils may be regarded as effectively excluded. Restrictions on physical grounds in many cases cannot be regarded as absolute restrictions. However, it should be possible on considerations of climate and soil to identify a number of products and product combinations which would be judged inefficient except under extreme economic conditions. This is to say that *a priori* considerations should serve effectively to weed out those products for certain subsectors which would not be regarded as falling within the economic range on the relevant production relations.

The above remarks imply the availability of a good deal of information regarding water input-crop yield relations. This is, in fact, not the case. Research in the physical production area has not in general been designed to obtain input-yield relationships over relevant ranges of water input. A good deal has been done, however, in attempts to develop water requirement per acre estimates for various crops for different soil classes under different climatic conditions. From what is known about physical soil-water phenomena,

as they relate to crop production, it is possible to establish working hypotheses bearing on the definition of activities to represent production of different crops in the activities analysis model. Review of the literature and consultation with specialists in the field suggests that the form of the yield-water input relation for given soil class and climatic conditions may be such as to permit satisfactory approximation by defining only one activity (that is, one input-output combination) along the relevant production function.

The approximate representation of a yield-water input relation suggested is shown in Figure 1. Assuming for the moment that soil flushing is not necessary the critical range in Figure 1 falls between wilting point (w.p.) and field capacity (f.c.). With a soil moisture content short of w.p., there would presumably be zero yield. Above f.c. yield would not be expected to increase in response to additional water input (except for the necessity of periodic flushing in some soils) and may decrease if subsoil texture is such as to cause "backing up" of the water table. The relation of yield to water input for fixed levels of other inputs between w.p. and f.c. may be regarded typically as the relevant range of physical relationship. Currently accepted theory seems consistent with the hypothesis that, as moisture content approaches w.p.

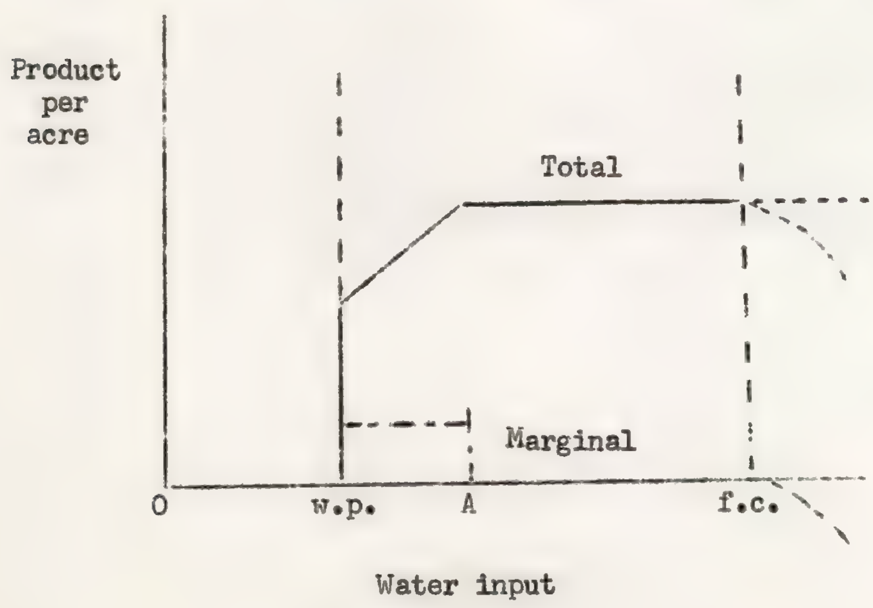

Figure 1.

from the right, a point is reached short of w.p. where stresses are set up in the plant, the net effect of which is reduced yield. At the same time, approaching f.c. from the left, yield stabilizes at some point considerably short of f.c. The impression gained from the literature is that the specific form of relation between w.p. and f.c. has not been established, at least for the range of conditions that might be desired for the present problem. The form of relation in Figure 1 may be regarded as consistent with theory, although both straight line segments of this relation must be regarded as approximations. It may be noted that the form of relation drawn implies that the range w.p. to A constitutes the relevant economic range of the production relation under a positive price of the water input.

The relation in Figure 1 is regarded as approximating the water-using relation in plant production. Assuming that such a relation can be developed from what is known (this relation may, in fact, be rather stable over soil types for similar climatic conditions), the amount of applied water required to bring the moisture content of the soil up to the indicated range and replenish it as necessary would, of course, vary depending on several key factors. The positions of w.p. and f.c. are closely related to soil type--primarily soil texture. In finer textured soils both points would presumably shift to the right. However, it may well be possible to locate these points within acceptable limits from what is known about physical properties of soils. The dominant effect of variation in other inputs such as fertilizer would presumably be to shift the level of the relation. The possibility of a joint effect on yield of water and fertilizer cannot be discarded since fertilizer would, in some cases, serve to increase vegetative growth relative to yield; and exposed foliage is an important determinant in transpiration losses.

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The combination of irrigation system and soil characteristics, such as texture and profile, would be dominant factors in determining the amount of

water required to bring moisture content to the desired range throughout a given field. Indeed for most irrigation systems in use, deep percolation at points of entry is unavoidable if the entire area is to be brought to at least the desired range, particularly in the other than fine textured soils. In such cases water percolating beyond the root zone must be regarded as water productively used since at the existing price structure it is probably economic to tolerate a fair amount of deep percolation rather than undertake the additional cost involved in modifying the irrigation system to one which effectively eliminates deep percolation. Finally, in certain soils periodic flushing is necessary in order to keep injurious salts below the root zone of plants being produced. Where such flushing is necessary, water so used should also be regarded as productively used.

Aside from soil characteristics, climatic factors must be explicitly recognized as effecting the yield relation. Under arid conditions the amount of water necessary to generate a given yield relation would be higher than under more humid conditions. A good deal of work has been done and is reported in the literature regarding the relation between climatic factors and consumptive use of water. Consumptive use refers to water used in plant growth and does not allow for excess application of water where excess application is in fact economic. Consumptive use closely parallels the water-input concept underlying Figure 1.

2. <u>Nonagricultural Activities</u>.--Subsectoring is convenient in the nonagricultural sector primarily as a device for incorporating explicitly alternative activities for certain heavy water-using industries. There are several industries sufficiently important as water users to warrant consideration for classification as separate subsectors. Examples are petroleum refining, steam electric generation, pulp and paper manufacturing, and steel mills.

water required to bring moisture content to the desired range throughout a given field. Indeed for most irrigation systems in use, deep percolation at points of entry is unavoidable if the entire area is to be brought to at least the desired range, particularly in the other than fine textured soils. In any case, water percolating beyond the root zone must be regarded as water productively used since at the existing price structure it is probably economic to tolerate a fair amount of deep percolation rather than undertake the additional cost involved in modifying the irrigation system to one which effectively eliminates deep percolation. Finally, in certain soils periodic flushing is necessary in order to keep injurious salts below the root zone of plants being produced. Where such flushing is necessary, water so used should also be regarded as productively used.

Aside from soil characteristics, climatic factors must be explicitly recognized as affecting the yield relation. Under arid conditions the amount of water necessary to generate a given yield relation would be higher than under more humid conditions. A great deal of work has been done and is reported in the literature regarding the relation between climatic factors and consumptive use of water. Consumptive use refers to water used in plant growth and does not allow for excess application of water where excess application is in fact necessary. Consumptive use closely parallels the water-input concept underlying Figure 1.

4. Nonagricultural activities.--Subsectoring is convenient in the nonagricultural sector primarily as a device for incorporating explicitly alternative activities for certain heavy water-using industries. There are several industries sufficiently important as water users to warrant consideration for classification as separate subsectors. Examples are petroleum refining, steam electric generation, pulp and paper manufacturing, and steel mills.

Subsectoring in heavy water-using industries facilitates specification of alternative input combinations for fixed output involving technical processes differing particularly with respect to water use. The economic conditions imposed in the problem would dictate the selection of a single activity for the subsector from among the alternatives specified. Note that this implies a simple form of limitational constraint on the demand side for the product produced in the industry concerned. An upper limit on volume of product produced at given finished product price is specified. A specification of this sort assumes a high degree of rigidity in product prices for the corresponding nonagricultural products in the short run. Such an assumption will in many cases not be unrealistic and its adoption results in some simplification of the problem.

Among the alternative activities defined for a heavy water-using industry would be represented alternatives varying with respect to amount of water re-use. Re-use of water has an associated cost which would show up in the corresponding activity as additional nonlimitational input. Because of the heavy use of water for cooling and broiler feed, recycling provides an obvious opportunity for water conservation. Under price relationships in which additional water intake becomes relatively expensive, industry would be expected to move more in the direction of technical processes involving re-use of water. In an activity involving a heavier degree of re-use, the additional nonlimitational input applied with a given water intake may be regarded as resulting in additional output--the water "produced" for re-use. Solving the program will select the most efficient activity from the set of alternatives under the conditions imposed. It is noted that the activities actually specified for the problem need only reflect <u>net</u> water input.

It is convenient to refer to the type of re-use described above as internal re-use. The possibility of external re-use should also be allowed in structuring the problem. External re-use involves the transfer of water

Interesting in heavy water-using industries facilitates specification of alternative input combinations for fixed output involving technical processes [illegible]

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produced in one activity to another activity where it enters as input. The major potential for external re-use arises from possibilities for recharge of underground reservoirs, reclamation of sewage, and reclamation of industrial waste water for re-use in outside productive activity. Operationally, the distinction between internal and external re-use is not an important one since net water inputs can be used directly in most cases in activities generating water for reclamation thus eliminating the necessity for specifying separate water reclamation activities.

Quality considerations apparently become important in formulations allowing for external as well as internal re-use. Cooling water in industrial production is rendered suitable for re-use through water-recooling processes involving loss through evaporation. Evaporation increases the mineral concentration in the water to the point where its use for certain purposes, such as irrigation, is virtually excluded. On the other hand, water used solely for transporting wastes in industrial production may retain quality characteristics when released from the system quite suitable for such uses as irrigation. This assumes that wastes transported are not themselves injurious in subsequent use. The quality of inferior water can be restored by treatment in most cases, although in the more extreme cases of deterioration associated with use, conversion of water back to suitable quality would likely involve costs which would be justified only under rather extreme situations of water scarcity. Conceptually, the problem should be defined so as to allow for reclamation of virtually all waste water. Operationally, however, it should be possible to define acceptable cutoff points beyond which it may be assumed that water in the form in which it emerges from a productive activity is not reclaimable under reasonable assumptions about the economic prospects and, hence, may be regarded as true waste at this point.

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The following impressions gained from review of literature thus far are suggestive of working hypotheses regarding the possibilities of reclamation for re-use. Loss of quality in cooling water used in industrial production, particularly where recycling is practiced, is apparently sufficient to question whether restoration to water of suitable quality for noncooling uses is likely to be economic under reasonable economic assumptions. Similarly, water used for transportation of waste in some industries can probably safely be regarded as thereby rendered unsuitable for further productive use. Water used in atomic reactors is an extreme example. Less extreme examples which may well also belong in this class are the petroleum-refining and soap and detergent industries. Water used in cleaning and transportation of waste in certain food-processing industries, on the other hand, emerge from the system apparently directly suitable for irrigation use. Use in such activity apparently affects quality primarily through an increase in organic content. Heavy treatment of the water may be necessary for other than irrigation uses unless its use for recharging underground reservoirs is economically feasible. Hence, agricultural production under irrigation may be the only feasible productive activity to receive as input water emerging as waste from the technical production processes defined for food processing. This would suggest vertical aggregation of food processing and associated irrigation activities.

Residential and commercial sewage as well as wastes from a good deal of the industrial sector may be regarded as possibly reclaimable at an economic cost. The possibilities lie in chemical treatment for a wide range of re-uses, involving treatment costs and associated costs of transporting the reclaimed water to points of subsequent use, or reclamation through return to underground water reservoirs. Costs of reclaiming may vary with use to which reclaimed water is to be put. Conceptually this should be recognized in a complete specification of the problem. Actually, since proliferation of water-distribution

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systems is probably economic only under rather extreme circumstances, reclamation of waste water will probably have to be allowed for on the assumption that the reclaimed water is to be brought to a quality suitable for use in that activity demanding the highest quality water. On the other hand, relatively short separate conveyance systems, carrying discharge from one operation directly to points of concentrated re-use not too far distant, may be economic. It is noted, also, that in some instances treatment costs alone may not render reclamation uneconomic, but the combination of treatment and transportation (pumping) costs may well do so. This is particularly relevant in California with large industrial concentrations on the coast in certain areas. Recapture of waste water for reclamation near the coast may involve conveying reclaimed water inland for re-use if, in fact, reclamation is an alternative source of water supply of significant magnitude.

Conceptually, the incorporation in the model of applied water for recharging underground water reservoirs and reclaimed waste water by chemical treatment (or, in fact, external re-use of untreated waste water) would be similar. There are two differences which perhaps need to be recognized explicitly: (1) Water used for recharge of underground reservoirs may be relatively inexpensive in that heavy application may be made in off-peak seasons and may be regarded to a certain extent as a process of capturing water which would otherwise be wasted, such as water released from surface storage in off seasons to achieve flood control. However, not all water used for recharging would fall in this class. (2) Water used for recharge may typically enter as input in a production activity of a later time period. In this sense water produced by a current activity constitutes a deferred input. Here again, however, not

all recharge water can be regarded as deferred input since to some degree the underground water reservoir may be regarded as an alternative conveyance system carrying water to other points in space for use as input in the current time period.[1/]

In the nonagricultural sector for other than heavy water-using industry, fairly comprehensive aggregation will no doubt be adopted. In part aggregation will be forced by paucity of data.[2/] Careful attention will need to be given

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1/ Whether recharge is for current or deferred use depends among other things upon the length of time unit defined for the analysis. A 6-month time unit appears convenient in the present problem with the 12-month period November-October broken into two 6-month components--November-April and May-October. This bears particularly on the measurement of product forthcoming from given activities. To illustrate, consider product associated with flood control in a surface water development project. Over a certain range of water storage capacity provided by projects of varying size, flood control requires planned release of water from storage during the November-April period when water requirements in certain other uses, such as irrigation, are low. This suggests that product forthcoming from downstream activities using water during the November-April period and flood control product may be regarded as complementary. On the other hand, activities which are active in their use of water only in the May-October period are independent or may, indeed, be considered as competing with product forthcoming from flood control. Whether the May-October activities are to be regarded as independent or competing with flood control is, of course, significant in forming the model since the specifications must admit activities in the two periods as alternatives if competition is to be effective. This requires dating of activities and the proper definition of limitational constraints. Clearly, formulation on the basis of the six-month time unit has merit in that it admits the possibility that optimum economic development for the state is in the direction of activities making relatively heavier use of the water input during the November-April period. This possibility is strengthened if a structuring of the state economy along such lines should permit a reduction in investment in water storage facilities from the magnitude otherwise required to support the present seasonal pattern of water-using activity.

2/ It is not intended to imply that there is an abundance of data suitable for defining alternative technical processes in heavy water-using industry. Suitable published data for this have not yet been uncovered, but search of the literature cannot at this stage be regarded as complete. This question, like others running through the proposed analysis, will require close consultation with operating and research engineers. There is basis for being optimistic about the possibility of uncovering unpublished data bearing on this problem in view of the growing concern in industry in recent years about water scarcity. In addition, there are several research projects currently in progress under the auspices of Resources for the Future, Inc., dealing directly with optimum resource combinations, including water as a key scarce input, in selected heavy water-using industries.

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to definition of activities representing low water requirement industry. The fact that water requirements are low does not constitute basis for dismissing this segment of the state economy as unimportant. Indeed, in analyses bearing on economic development under conditions of water scarcity, optimal development may well be in the direction of substantial growth of low water-using relative to heavy water-using industry. This is particularly true in analyses centering on a given state or region as long as there exists possibilities for development of heavy water-using industry in other regions where water scarcity promises to be less serious. Inclusion of properly specified low water requirement activities in the model for California allows development in this direction as a part of the optimizing solution for this state.

This point should not be overplayed, however, since the importance assumed by such activities can only be expected to be fully reflected if there is adequate provision for the effects of interregional competition. As has been noted, it is one of the weaknesses of the present formulation that interregional competition is largely disregarded. At best only partial allowance will be made for such factors in initial attempts at empirical analysis--this allowance being made through the demand characteristics introduced for particular products.

Illustrative Activities

A set of illustrative activities is presented in Table 1 in more amplified form. Although the coefficients are still specified in abstract terms, a measure of concreteness is achieved by attaching labels to the "commodities" and by specifying zeros for certain cells of the table. It will suffice to regard the activities defined as referring to a single major sector since the purpose is only to illustrate selected important types of activities which it would seem plausible to allow for in the problem at hand. A further simplification in notation is achieved by numbering activities continuously over subsectors.

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Illustrative Activities

A set of illustrative activities is presented in Table I in more explicit form. Although the coefficients are still specified in abstract terms, a measure of concreteness is achieved by attaching labels to the "commodities" and by specifying zeros for certain cells of the table. It will suffice to regard the activities defined as referring to a single major sector since the purpose is only to illustrate selected important types of activities which it would seem plausible to allow for in the problem at hand. A further simplification in notation is achieved by numbering activities continuously over

[illegible]

TABLE 1

Area s

	Agriculture-based activity								Nonagricultural activity			
	Soil class A					Soil class B						
	Deciduous fruit for processing			Hay, grain, livestock		Hay, grain, livestock		Pasture, livestock	Pulp and paper		Other industry	
											A	B
	1	2	3	4	5	6	7	8	9	10	11	12
Gross product												
Principal product	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	$a_{1,10}$	$a_{1,11}$	$a_{1,12}$
Secondary products												
Retailing	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}	a_{28}	a_{29}	$a_{2,10}$	$a_{2,11}$	$a_{2,12}$
Service	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}	a_{38}	a_{39}	$a_{3,10}$	$a_{3,11}$	$a_{3,12}$
Wholesaling	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}	a_{47}	a_{48}	a_{49}	$a_{4,10}$	$a_{4,11}$	$a_{4,12}$
Water produced												
Internal	0	0	0	0	0	0	0	0	a_{59}	0	0	0
External	0	0	a_{63}	0	a_{65}	0	0	0	0	$a_{6,10}$	$a_{6,11}$	$a_{6,12}$
Nonlimitational inputs												
Depreciation:												
Internal water recl. system	0	0	0	0	0	0	0	0	$-a_{79}$	0	0	0
Water spreading facility	0	0	$-a_{83}$	0	$-a_{85}$	0	0	0	0	$-a_{8,10}$	$-a_{8,11}$	$-a_{8,12}$
Irrigation system	$-a_{91}$	$-a_{92}$	$-a_{93}$	$-a_{94}$	$-a_{95}$	$-a_{96}$	$-a_{97}$	$-a_{98}$	0	0	0	0
Drainage system	0	0	0	0	0	$-a_{10,6}$	$-a_{10,7}$	0	0	0	0	0
Other fixed assets	$-a_{11,1}$	$-a_{11,2}$	$-a_{11,3}$	$-a_{11,4}$	$-a_{11,5}$	$-a_{11,6}$	$-a_{11,7}$	$-a_{11,8}$	$-a_{11,9}$	$-a_{11,10}$	$-a_{11,11}$	$-a_{11,12}$
Materials input (excluding fertilizer)	$-a_{12,1}$	$-a_{12,2}$	$-a_{12,3}$	$-a_{12,4}$	$-a_{12,5}$	$-a_{12,6}$	$-a_{12,7}$	$-a_{12,8}$	$-a_{12,9}$	$-a_{12,10}$	$-a_{12,11}$	$-a_{12,12}$
Fertilizer	0	$-a_{13,2}$	$-a_{13,3}$	0	$-a_{13,5}$	0	$-a_{13,7}$	0	0	0	0	0
Limitational inputs												
Land area	$-a_{14,1}$	$-a_{14,2}$	$-a_{14,3}$	$-a_{14,4}$	$-a_{14,5}$	$-a_{14,6}$	$-a_{14,7}$	$-a_{14,8}$	$-a_{14,9}$	$-a_{14,10}$	$-a_{14,11}$	$-a_{14,12}$
Labor												
Principal product	$-a_{15,1}$	$-a_{15,2}$	$-a_{15,3}$	$-a_{15,4}$	$-a_{15,5}$	$-a_{15,6}$	$-a_{15,7}$	$-a_{15,8}$	$-a_{15,9}$	$-a_{15,10}$	$-a_{15,11}$	$-a_{15,12}$
Secondary products	$-a_{16,1}$	$-a_{16,2}$	$-a_{16,3}$	$-a_{16,4}$	$-a_{16,5}$	$-a_{16,6}$	$-a_{16,7}$	$-a_{16,8}$	$-a_{16,9}$	$-a_{16,10}$	$-a_{16,11}$	$-a_{16,12}$
Applied water												
Principal product	$-a_{17,1}$	$-a_{17,2}$	$-a_{17,3}$	$-a_{17,4}$	$-a_{17,5}$	$-a_{17,6}$	$-a_{17,7}$	$-a_{17,8}$	$-a_{17,9}$	$-a_{17,10}$	$-a_{17,11}$	$-a_{17,12}$
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Residential use	$-a_{19,1}$	$-a_{19,2}$	$-a_{19,3}$	$-a_{19,4}$	$-a_{19,5}$	$-a_{19,6}$	$-a_{19,7}$	$-a_{19,8}$	$-a_{19,9}$	$-a_{19,10}$	$-a_{19,11}$	$-a_{19,12}$

Secondary Products

Simplifications have been introduced in an attempt to construct something approaching an operational framework for analysis. Secondary products forthcoming from retailing, wholesaling, and service industries are included in the illustrative activities as joint products. The inclusion of secondary products in activities defined for principal products may be regarded as resulting from aggregation of less comprehensive activities along the lines referred to previously. The alternative is to deal with less comprehensive aggregates in which case additional constraints on the relationship between levels of related activities would need to be imposed explicitly. The aggregation procedure in this instance is equivalent to imposing a constraint of proportionality on the related less comprehensive activities.

Not all secondary products have been included in the illustrative specification. Productive activities such as construction, transportation, finance and real estate, and government may also be regarded as secondary to principal activities such as manufacturing and agriculture. It is proposed that these activities also be incorporated explicitly in the formulation either as secondary products in more comprehensive activities or as separate activities with appropriately defined constraints.1/ Since the proportionality restriction

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1/ In adapting the model to a form suitable for empirical analysis the adoption of nonagricultural commodity composites conforming to the Standard Industrial Classification is unavoidable since heavy reliance will be on data published by the U. S. Bureau of the Census and other agencies also using this classification. In addition, various analyses pertinent to the present problem have dealt with commodity composites based on this classification. Measures of net product will not be directly available, although for manufacturing industries a closely related measure, "value added," is available. Published data on industrial water input are inadequate in detail. However, recent and continuing investigations by the California Department of Water Resources in the San Francisco and Los Angeles-San Diego areas should provide data which will partially remedy this deficiency.

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is not strictly valid, its imposition results in a loss of precision in the optimizing solution. On the other hand, its approximate validity coupled with the substantial simplification achieved may be regarded as sufficient basis for its adoption rather extensively in the exploratory phase of quantitative analyis.

Primary Joint Products

Primary joint products associated directly with surface water development have been omitted from the activities defined. Primary joint products refer to the "other purposes" of multiple purpose project development. Major examples are flood control, hydroelectric generation, navigation, and recreation. These products are excluded in the exploratory phase primarily to simplify the formulation. Although clearly joint products of an over-all water development and management program, the proportionality implied by their inclusion in activities such as those illustrated would seem more questionable a priori than in the case of secondary joint products. Product forthcoming from flood control, for example, would certainly not increase linearly throughout the range of activity levels. A point is reached presumably beyond which additional releases from storage would result in zero expected product from flood control. Similarly, an upper limit to hydroelectric generation having value would seem realistic from the combined demand and technical production points of view. The relation of navigation product to activity level is probably subject to restrictions at both extremes. From purely technical considerations it would seem plausible a priori that certain minimum channel flows are necessary before any navigation product is forthcoming at all and that beyond a certain pattern and rate of flow navigation product would not respond to increases in channel flow.

One way of dealing with primary joint products is through iterative procedures which do not incorporate them explicitly in the problem as initially formulated. This is the procedure contemplated here. First, an optimum program

[illegible] not strictly valid, but [illegible] in a form of [illegible] in the [illegible], however, in the [illegible], the [illegible] with the [illegible] simplification [illegible] sufficient [illegible] exclusively in the [illegible] of [illegible].

[illegible]

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The use of [illegible] joint products is [illegible] which do not incorporate [illegible] in the [illegible] formulated. [illegible]

is defined excluding these products. The total primary joint product implied by the distribution and level of water flow required to support the optimum program could then be ascertained. It should be possible further to approximate the additional primary joint product forthcoming from alternative water regulatory practices (including additional investment implied) departing from that required for the optimum combination of explicitly defined activities. A systematic procedure for exploring the consequences of such modifications should be possible to develop. With respect to activities defined explicitly for supplemental analysis of joint products, the relevant modifications in regulation of flow or in total water resource available would show up in changes in water limitational constraints for specified sets of activities. Technically this implies a programming solution of a subsidiary problem in which product forthcoming from flood control is included explicitly in the criterion to be maximized. In an actual problem, however, the arithmetic of the solution may be relatively straightforward and simple. The construction of appropriate measures of product forthcoming will be more difficult but meaningful assessment of product should be possible. Procedures appropriate for handling flood control should also be adaptable to navigation and hydroelectric generation.

Although problems of measurement promise to be troublesome throughout an analysis of the sort contemplated, the development of quantitative measures of a product like recreation is particularly difficult. Attempts have been made to develop standards for direct measurement and some such procedure could be adopted in the present problem. However, a rather natural alternative procedure may have merit in this instance. For a given project, additional investment and operating costs identifiable with the recreation purpose might be regarded as one component of the measure of product. In those cases where recreation competes with alternative uses for the limited water resource there

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exists an additional component equivalent to alternative product foregone. In the approach here proposed it should be possible to obtain approximations to alternative product foregone implied by different levels of diversion from programmed activities to recreation use. The sum of direct costs and alternative product foregone could then constitute the measure of recreation product.

An alternative procedure for including primary joint products which has the merit of including them explicitly as a part of the initial problem might be to extend the aggregation to include them explicitly in the relevant subset of activities along with constraints allowing nonzero joint product only up to a predesignated combined level of activity. This implies constructing parallel subsets of activities including and excluding the primary joint products. This could be done in a manner which would insure that a given augmented activity would be more efficient than its parallel activity thus insuring that the augmented activity would be activated first. Definition of an augmented activity for every original activity is not implied. Navigation, for example, might well be competitive in water use with activities located above the Sacramento-San Joaquin Delta and, at the same time, complementary to those uses below the Delta. This implies that the inclusion of primary joint products could alter the optimal regional distribution of water use.

In the formulation here proposed, product forthcoming from hydroelectric generation may be realistically regarded as produced input since electric energy enters as an important input in the water distribution system. On the other hand, alternative uses do exist for the electric power produced and alternative activities for its generation (steam plants) are operative and should be incorporated explicitly in the model. This suggests that in the definition of activities, including hydroelectric energy as a joint product, procedures analogous to those described above for water recycling may be

[illegible]

[illegible]

[illegible]

[illegible]

appropriate. Alternative steam electric generation activities should be specified, however, to insure that the most efficient source or combination of sources of electric power is not precluded from the optimum development program.

Differentiation of Activities

Certain other commodities identified in Table 1 have been broken down in some detail to differentiate the activities defined for a particular subsector. Attention is focused here on differentiation achieved by the assignment of zero values to selected input and output coefficients, although it should be understood that corresponding nonzero coefficients in alternative activities may also differ. Accordingly, soil classes A and B in agriculture-based activity are differentiated to recognize explicitly the drainage problem potential in B which does not exist in A. Furthermore, within soil class B it is assumed that a drainage problem exists for a hay-grain-livestock activity but not for pasture-livestock. This is reflected by the inclusion of amortization of drainage investment in 6 and 7 but not in 8. Activities 6 and 7 are differentiated by the inclusion of fertilizer input in the latter and not in the former. A similar distinction appears in 1 and 2. Activities 3 and 5 differ from their counterparts within respective subsectors in that underground water recharge is included explicitly. In each case investment in water-spreading facilities has been assumed, although such investment is not implied in all activities with nonzero external water produced.[1/]

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1/ The construction of suitable measures of investment in water reclamation, irrigation, and drainage systems depends upon the availability of appropriate data from engineering studies. A systematic search of relevant literature has not yet been undertaken. Consultation with the engineer will in any case be necessary to supplement published information and to adapt specific results to the more general orientation of the present problem.

In nonagricultural activity pulp and paper has been included to illustrate heavy water-using industry. Internal water recycling is specified in 9 while ground water recharge is included in 10. In heavy-water-using industry under conditions of scarce water resources, activities with zero internal water produced will probably not be efficient and, accordingly, can be deleted from the set of alternatives considered. Such considerations are disregarded in the present illustrative specification.

Categories A and B under "other industry" refer in each case to aggregates of activity in which water does not constitute an important input. Differentiation in activities here is based on such factors as demand characteristics for product or input coefficients of other limiting resources. As has been indicated, the inclusion of such activity is necessary to allow economic development in the state (or in certain regions within the state) to take directions not heavily dependent on scarce water resources.

Concluding remarks

Clearly, the illustrative activities defined in Table 1 are not proposed as a realistic representation of the complete set necessary for a given major area. For meaningful substantive results a relatively large number of activities may need to be defined for a major area, such as, for example, the San Joaquin Valley. As has been indicated, this implies the availability of a good deal of data. Unfortunately, the survey of literature to date suggests that rather less is known about certain of the underlying physical phenomona and technical relationships than may be implied by the structuring of the present problem. On the other hand, a systematic attempt at constructing suitable measures of activities incorporating the features discussed would appear clearly worthwhile. The adequacy of present knowledge and the possibilities of quantitative adaptation based on data presently accessible cannot be fully assessed until such a systematic attempt has been made.

Certain gaps in knowledge may be bridged by assumption without serious loss. Other assumptions will, no doubt, be necessary for which the loss may be more serious and indeed may not lend itself to easy assessment. Although heavy reliance on assumption or measures of questionable suitability may lead rather early to serious question concerning precision of substantive results, exploratory analyses should still be fruitful. In the extreme event of heavy reliance upon assumption the approach proposed is regarded as still having merit on at least two counts. First, crucial assumptions become rather conspicuous and, secondly, a systematic procedure is provided for exploring the consequences of alternative assumptions which may seem *a priori* equally plausible. Pinpointing the consequences of gaps in data should thereby be facilitated.

It may be noted that while extra institutional constraints have not been made explicit in this discussion, the procedure proposed can easily be adapted to accommodate such constraints. The assignment of priority to residential use, for example, may be incorporated by prior deduction of total residential requirement from available water supply and proceeding with the optimization problem net of this prior allocation. It should be noted, however, that from an economic point of view a constraint of this character is clearly arbitrary since, being defined exogenuously, it may preclude the industrial development essential for employment of the resident population. Similarly, restrictions imposed exogenously through a particular pattern of water rights may be incorporated explicitly.

Upon full quantitative implementation there emerges a set of discrete activities for a given time period or, for explicit extension in time, sets of discrete activities for a succession of time periods. The procedure selects under the constraints imposed that subset of activities which maximizes net product. Referring to the optimal subset of activities as an optimal program,

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comparison of alternative water development projects or alternative integrated systems involves comparison of outcomes of a series of optimal programs. Accordingly, dams of varying capacity at a given site may be compared. Also, alternative dam sites or alternative integrated systems for a river basin may be compared. In comparing programs it would appear more informative for investment decision to hold constraints on limitational resources other than water fixed while the constraints on the water resource are allowed to vary. Alternative water development systems imply different levels of investment. Measurement of net product associated with alternative optimal programs corresponding to a range of levels of water resource investment for fixed levels of other resources provides one measure of incremental product associatdd with added investment.

Although conceptually suitable for measurement bearing on water investment decision, it should be repeated for emphasis that the development of a conceptual scheme is not the end objective. The validity and precision of the actual quantitative measures emerging in applied analysis are after all of primary importance. In view of the paucity of strictly appropriate data and the important bearing of risk and uncertainty for extensions in time it is inevitable that substantive results forthcoming from applied analysis will need to be interpreted with a great deal of caution. Related to this is a particularly troublesome aspect of the approach in applied analysis stemming from a dangerous susceptibility to "built-in" results.

Exploratory Problem Area

The procedure discussed above is regarded as a method for quantitative analysis of optimum investment in water resource development in a comprehensive setting such as for the state as a whole. For exploratory analysis, scaling down the dimensions of the problem is highly desirable. The definite problem

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area has not yet taken concrete form and hence cannot be outlined specifically in this statement, but some remarks bearing on this question are offered.

There is clearly an advantage to scaling down the problem in a manner which preserves essential features of the more comprehensive model. Accordingly, the retention of a meaningful water allocation problem geographically and productwise is indicated. Initially it will be convenient to suppress the time dimension by defining measures in terms of annual rates for the life of a project. Later, however, the time dimension should be incorporated explicitly since, short of such extension, crucial factors related to optimum economic development cannot be introduced.

Comparison of major alternative surface water development projects need not be regarded as an immediate goal. Attempts at analysis centering on a single major project may be expected to provide insight into the method bearing directly on the broader problem implied in the comparison of alternative projects. Local water development in various regions of use should be explicitly recognized in the initial work, although devices may be found for avoiding the proliferation of activities implied if they are to be fully incorporated in the model. Production of water through recycling, including underground recharge, should be made explicit. Finally, attention to methods of dealing with the nonlinearities implied by less than infinitely elastic product demands and desreasing per unit costs in water distribution should be an integral part of exploratory analyses.

A concrete problem centering on a self-contained component of the Feather River Project appears to be the most promising for this initial phase. A central feature of this project is the provision for extensive geographic distribution of the captured water resource. Interest in this project in recent years has motivated a good deal of work in civil and irrigation engineering, agricultural production research, and in other areas which have immediate bearing on the accessibility of data for the present analysis.

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There is clearly an advantage to scaling down the problem in a manner which preserves essential features of the more comprehensive model. Accordingly, the exposition of a regional water allocation problem sequentially and contiguously is indicated. Initially it will be convenient to suppress the time dimension by defining resources in terms of annual rates for the life of a project. Later, however, the time dimension should be incorporated explicitly since, short of such extensions, crucial factors related to optimum economic development cannot be introduced.

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Although important directly relevant data available in published form, such as engineering estimates of project costs, are regarded as tentative by the authors, work is continuing currently and later modifications of estimates may be obtainable through direct consultation. A substantial part of the measurement problem deals with magnitudes which are independent of the specific project generating water supplies. Therefore, measures developed and the operational framework which emerges should be directly adaptable to analysis of other specific projects, providing a basis for economic appriasal of alternative surface water development programs.

Summary

A method has been outlined for quantitative economic analysis of water resource development and allocation under conditions of economic growth. A matrix of activities classified by major sectors and subsectors is defined which, when constructed to incorporate relevant economic conditions, constitutes the set of activities with respect to which the economic optimum is defined. The criterion of optimality proposed is a measure of net product for the California economy as a unit. Ideally, all economic activity in the state should be represented in the model. The resources recognized as limitational are land area, labor force, and applied water. By appropriate definition of limitational constraints for the state as a whole, for major sectors, for subsectors, or for some combination of these, meaningful approximations to economic optima under realistic conditions should be achievable. The model is not extended explicitly in the time dimension, although remarks beaing on such extension are offered.

Homogeneity of input-output vectors is the basis for classification of activities by sectors and subsectors. Strict homogeneity would require definition of a very large number of activities; indeed, exceeding the number

of microeconomic units generating the state's economic product. Accordingly, procedures of aggregation are discussed which might be expected to control the loss of precision associated with combination of microactivities. Homogeneity with respect to both technical production and product demand characteristics governs aggregation. Thus, in agricultural activity such physical factors as climate, soil class, and topography as they bear on technical production relations are relevant as well as product demand characteristics reflected primarily by price and income elasticity. Explicit introduction of other than infinitely price elastic product demands implies nonlinearity in the optimality criterion. With respect to certain agricultural products this complication cannot be avoided if meaningful optimizing solutions are to be forthcoming. For other agricultural products, such as those under governmental production restriction, demand constraints in the form of a maximum allowable level of production at fixed prices would seem appropriate. In nonagricultural activity physical factors do not have the same direct effect on homogeneity of input coefficients as in agricultural production. Here, the differentiation in activities is based ideally on the technical processes associated with type of product, or perhaps alternative technical processes for a given type of product. Demand constraints imposing maximum allowable product for a given time unit at fixed prices would seem generally more plausible for nonagricultural than for agricultural products. Aggregation procedures in this case will be dominated by considerations of homogeneity of input coefficients for the several limitational resources. Operationally, the types of data available will unquestionably force a level of aggregation broader than what might be considered optimum, particularly in the exploratory phases of the analysis.

Major sectoring by geographic delineation is proposed primarily to facilitate measurement of the applied water input and secondarily to achieve a measure of climatic homogeneity. Major sectoring also provides a possible plausible basis with reference to which certain resource limitational

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constraints may be defined. Naturally separable geographic areas with respect to costs of water distribution facilities are envisioned. Major sectoring is not expected to achieve sufficient homogeneity with respect to cost of applied water, however, since systematic variation in water distributional costs within major sectors may be rather significant. This is troublesome in this instance since the cost of applied water input within a major sector is not independent of the activity level vector. As in the case of certain product demands, the nonlinearity in the optimality criterion implied by decreasing costs in the main water distribution system is probably sufficiently important to require that it be made explicit in the operational model.

It is proposed to deal with secondary products forthcoming from water resource development as strictly complementary with principal direct products by including them as joint products in the activities defined. This is equivalent to defining separate activities for principal and secondary products and imposing, in addition, a constraint of proportionality on demand. Secondary products include such composites as retailing, wholesaling, personal service, transportation, communications, finance, construction, and government. The proportionality condition imposed is, of course, only approximately valid and subsequent more adequate appraisal of the consequences may lead to modifications in directions which are more acceptable.

In this preliminary formulation primary joint products such as flood control, navigation, hydroelectric energy, and recreation have not been incorporated in the initially defined activities. The major reason for omission of the first three of these stems from the <u>a priori</u> basis for rejecting the linearity assumption. With respect to recreation, nonmeasurability of net product is a dominant factor leading to its exclusion in this initial phase. Although not included explicitly, subsidiary analyses along lines suggested in the body of this statement provide for systematic inclusion of these important

joint products at a subsequent stage. It is possible, though perhaps not likely, that these "other uses" of captured surface water will turn out not to be competitive with the regulatory and management practices implied by the optimum combination of initially programmed activities excluding them. In that event, subsequent allowance for these products in the aggregate measure of product forthcoming should be relatively straightforward.

Exploratory empirical analyses based on partial skeleton models is a logical next step. It is contemplated that initial attempts will concentrate on problems of allocation in space--geographically and productwise--for a given period of time. Subsequent extension in the time dimension is essential, however, for dealing realistically with the problem of economic development. In the operational setting, key elements of the problem requiring explicit recognition for extensions in time center around growth of demand for products, changes in technology, and changing supplies of limitational resources. More adequate recognition of the important economic implications of interregional competition and intrastate industrial location is also important to meaningful substantive results in a context of growth.